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Experimental verification of elastomeric bearings according to STN EN 1337-3

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Abstract

The aim of this paper is to demonstrate the behavior of reinforced elastomeric bearings under various types of loads. They were made of special types of bearings to demonstrate an effect of reinforcing of bearing. The experimental verification of these special bearings has been tested on three standard types of loading – compressive load, shear and restoring moment. The results of the experimental measurements are compared with the results of numerical modeling and calculations according to standard assumptions in STN EN 1337-3. In the conclusion, the results are summarized for the selected types of bearings. The results shows that behavior of the bearings is not always be as envisaged by standard, particularly in terms of bending moment loading.

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*Keywords:*bearing, elastomeric bearing, testing, STN EN 1337-3

1. Introduction

Elastomeric bearings have been used in bridge engineering since the 60´s. Nowadays, some modifications of the shape and functions of the material are taking place. The latest trends in this field are the use of carbon fiber instead of steel reinforcing plates and the use of bearings as an insulator of unwanted movements with various design modifications or various modifications to the elastomer material itself. The design and construction requirements are based on standardized relations and recommendations, which are valid only for the basic types of reinforced elastomeric bearings. Since they started to be used, there have been no constructional changes or adjustments. In

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Slovakia is not possibility to make an atypical bearing –using a carbon fiber instead of steel reinforcing plates. The authors tried it, but without success. Therefore it has been working with bearings with steel plates, but with modified parameters. The paper deals with the effects of reinforcements, primarily the number of an elastomeric layers and their thickness.

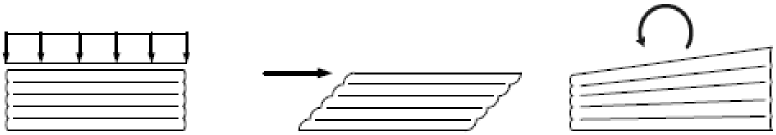

Fig. 1 The bearings loading schemes

1.1. Effect of the thickness of an elastomer layer

Fig.2 represents the non-linear dependency of vertical deflection v_z on a maximal vertical load at a constant thickness (5, 7.5, 10 and 12.5mm) of an elastomer layer. According to formula (2) vertical deflection depends on three variable values – the effective area $A_{eff,}$ the thickness of the individual elastomer layer t_i and the shape factor S. It can be seen that anincrease of thickness of elastomer layer results in a decreased maximal vertical load and increased vertical deflection. The maximal vertical load, maximal vertical deflection and shape factor of the bearing are given by the following formulas:

$$F_{z,d} = \frac{5 \cdot G \cdot A_{eff} \cdot S}{1.5} \tag{1}$$

$$v_z = \Sigma \frac{F_z \cdot t_i}{A_{eff}} \cdot \left(\frac{1}{5 \cdot G \cdot S^2} + \frac{1}{E_b} \right) \tag{2}$$

$$S = \frac{a_{eff} \cdot b_{eff}}{2 \cdot \left(a_{eff} + b_{eff} \right) \cdot t_E} \tag{3}$$

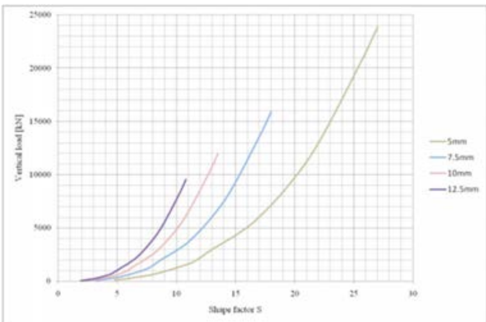

Fig. 2 Dependence of maximal vertical load on the shape factor for thickness of 5, 7.5,10 and 12.5mm elastomer layers

The graph and formulas shows that the number of elastomeric layers (symbol ni according EN 1337-3) does not have an influence on the allowed vertical load, vertical deflection, and shape factor. The result is that standard EN 1337-3 does not expect a nonlinear behavior of elastomeric bearing and no influence of number of elastomeric layers on maximal load. These effects have been verified by numerical modeling and experimental testing in next part of the work.

2. Testing methods

Nowadays, the current STN EN 1337-3 standard recommends three methods of testing elastomeric bearing. This results from the three reactions most often, from a load-bearing structure – vertical load, horizontal movement and rotation. These reactions are verified by the compression test method, shear modulus test method and restoring moment test method. The bearings described in Tab. 1 and Fig. 3. were designed for the experimental verification.

Tab. 1 Numbering of bearing and dimensions and number and thickness of layers

number	TYPE	A [mm]	B [mm]	$n_{el\ layers}$	T_{01} [mm]	t_E [mm]	layers [mm]
17	1	100	100	5	42	5	2.5+2+5+2+5+2+5+2+5+2+5+2+2.5
7		100	150	5	42	5	2.5+2+5+2+5+2+5+2+5+2+5+2+2.5
16		100	100	3	43	10	2.5+2+10+2+10+2+10+2+2.5
6		100	150	3	43	10	2.5+2+10+2+10+2+10+2+2.5
15		100	100	3	43	7,5	5+2+7.5+2+10+2+7.5+2+5
5		100	150	3	43	7,5	5+2+7.5+2+10+2+7.5+2+5
14	2	100	100	2	42	5	15+5+2+5+15
4		100	150	2	42	5	15+5+2+5+15

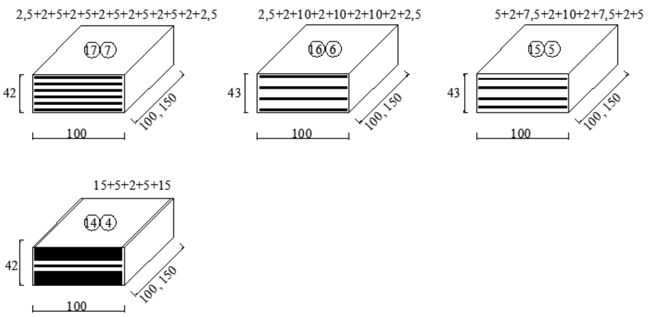

Fig. 3 Bearings designed for the experimental testing

2.1. Compression test method

A compressive load occurs in every field of the application of elastomeric bearings. The deformation of the bearing is influenced by the use of reinforcing layers. The main parameters of the compressive load are the maximal vertical force, vertical deflection, and the modulus of elasticity in compression EC. The test consists of measuring the compression of an elastomeric bearing when subjected to increasing compressive loads. Testing procedure specified by the standard [1] is shown in Fig. 4a.

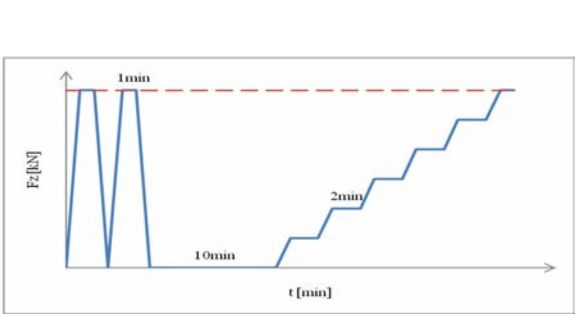

Fig.4 (a)Testing procedure for the first loading according to standard EN 1337-3 (b) Testing equipment

The standard [1] recommends three level testing procedures, where the test piece should be placed at the centre of the testing platen. The maximum load (1) shall be applied to the bearing, held for 1 min and then removed. The recommended loading speed is 10 MPa/min. This process is repeated so that two complete loading and unloading cycles are carried out. After a further 10 min under zero load, the next load is applied progressively with a minimum of six increments. At each measuring point, the load is maintained at a constant value for a minimum 2 min. to minimize the viscoelastic effects. After the first loading, the maximum compressive load is applied progressively with a minimum of five increments at a rate of 5±0.5 MPa.

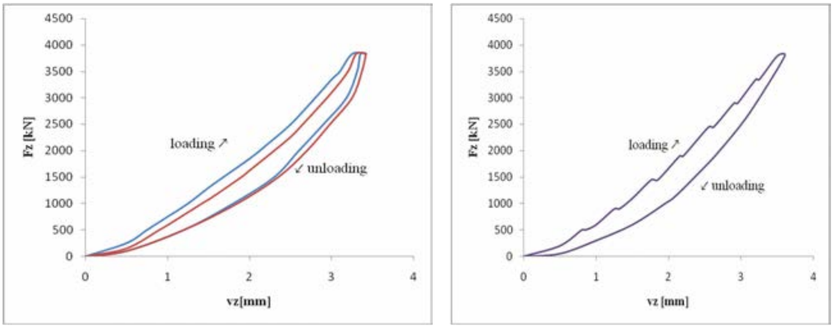

Fig.5 (a) Vertical deflection in first loading –level I,II (b) level III

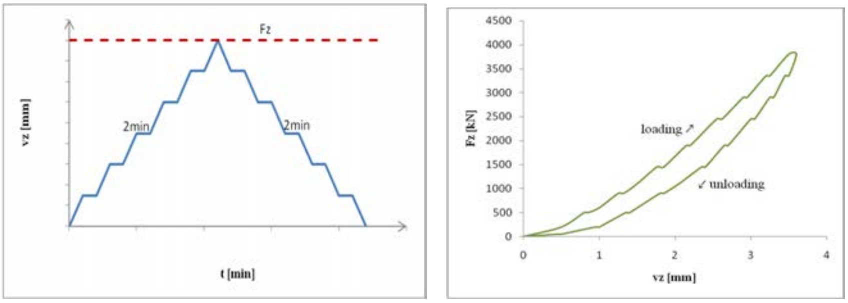

Fig.6 (a) Testing procedure (b)vertical deflection according to standard EN 1337-3in second loading

2.2. Shear modulus test method

The test consists of measuring the shear deflection of a pair of identical bearings, when they are subjected to increasing shear loads. From these measurements, the apparent shear modulus is calculated.

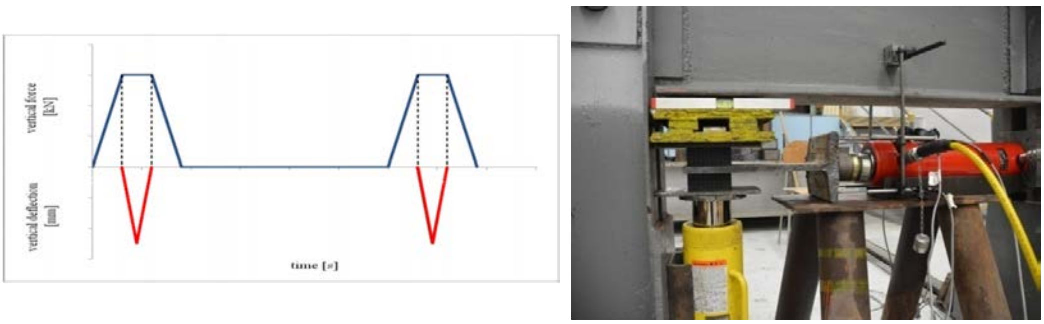

Fig.7 (a) Testing procedure for shear modulus test method (b)Testing equipment for the shear modulus

The test pieces should be placed symmetrically on each side of the moveable plate so that the shear direction is across the width of the bearing. A mean pressure of 6 MPa should be applied. Then the bearings should be subjected to a shear at a constant and maximum speed of 150mm / minute to the maximum test deflection of 80% of the total initial thickness of the elastomer (Te) and then returned to zero deflection. The compressive load should be removed and the test pieces left undisturbed for five minutes. The cycle, should then be repeated

A conventional shear modulus is obtained from the measurement using:

$$G_g = \frac{\tau_{s2} - \tau_{s1}}{\varepsilon_{s2} - \varepsilon_{s1}} \tag{4}$$

where:

τ_{s2} is the shear stress and εs2 the shear strain at a deformation of $v_{x2} = 0.58.Te$

τ_{s1} is the shear stress and εs1 the shear strain at a deformation of $v_{x1} = 0.27.Te$

2.3. Restoring moment test method

The restoring moment is defined as the moment required to rotate a bearing through a required angle. This type of load in bridge engineering is caused by a traffic load.

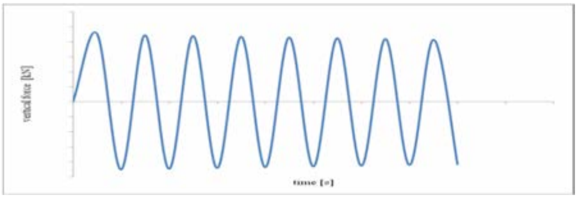

Fig.8 (a) Loading process (b) Testing equipment for restoring moment test method

The moment is applied through a lever arm between two identical bearings. The bearing should be rotated at a specified frequency while being subjected to the specified compressive load for 10 cycles. The force on the lever arm should be recorded. The experimental value of restoring moment is given by the expression:

$$M_e = \frac{(F_{z1} - F_{z2}) \cdot L}{4} \tag{5}$$

where:

F_{z1} and F_{z2} are the positive and negative values of the load at the tenth cycle to the lever arm, at the distance l from the centre of the bearing.

3. Numerical modeling

The numerical modeling was carried out using software ANSYS, which works according to the finite element method. The modeling of individual loading case is dependent on the type of stress. For the shear modulus test method and restoring test method parts for applying horizontal and vertical movements (fig. 10, 11) were modeled according to the actual testing. The bearing was built from individual layers and then supporting and load were applied. Symmetry for an half bearing was used for faster calculation. Neo-Hook material model was used for representing elastomer. An elasto-plastic material model with a defined working diagram from tensile test of steel sheet was used for steel sheet. The type of element used was 3-dimensional, 20-node structural SOLID 186 with three degrees of freedom per node.

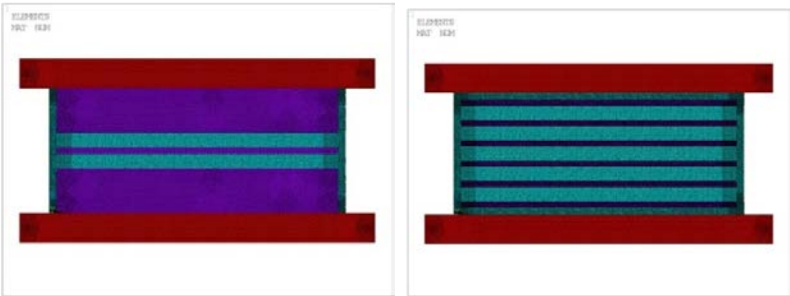

Fig.9 Numerical model for the compression test method for bearings 14 and 17

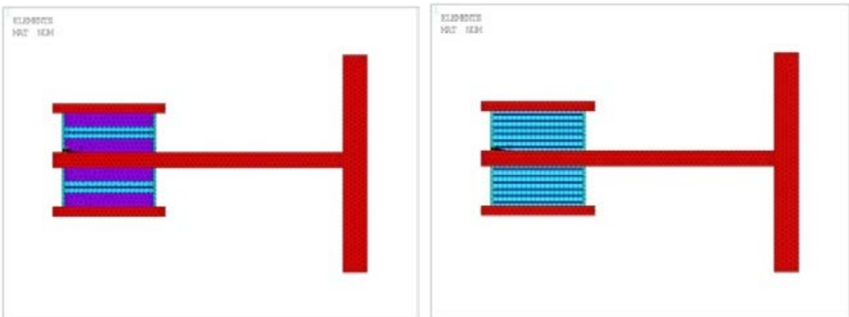

Fig.10 Numerical model for the shear modulus test method for bearings 14 and 17

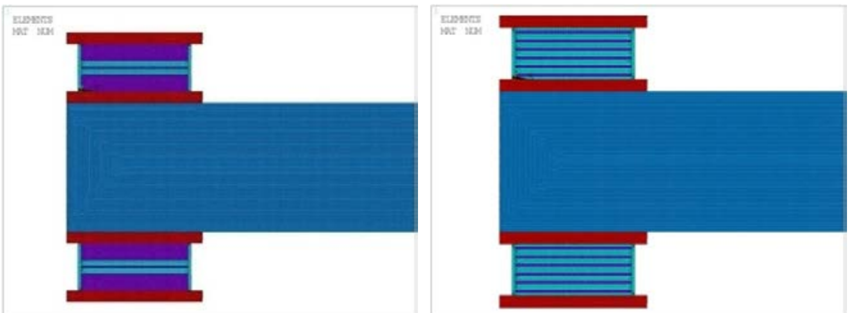

Fig.11 Numerical model for the restoring moment test method for bearings 14 and 17

4. Results

The vertical deflection and modulus of elasticity in compression are the resulting values from the compression test method. From the loading in shear the value of the modulus of elasticity in shear resulted and from resistance to rotation it is restoring moment. The values from experimental testing were compared with values according to the standard STN EN 1337-3 and the values from the numerical modeling. The bearings above the double line are from type 1 and below are from type 2 (Fig.3).

Tab. 2 Results from the compression test method – vertical deflection [mm]

number	A [mm]	B [mm]	STN EN 1337-3	ANSYS	experimental			
					1st level	2nd level	3th level	second loading
17	100	100	3.687	3.427	3.010	3.015	3.114	3.249
7	100	150	3.119	2.736	2.344	2.457	2.580	2.323
16	100	100	8.528	4.134	3.377	3.438	3.555	3.575
6	100	150	7.098	3.844	3.757	3.816	3.917	3.441
15	100	100	7.019	3.92	4.251	4.48	4.556	4.435
5	100	150	5.854	3.638	3.707	4.088	4.168	3.838
14	100	100	1.475	1.482	1.489	1.517	1.549	1.763
4	100	150	1.248	1.249	0.896	0.946	0.986	0.966

Tab. 3(a) Results from the compression test method – modulus of elasticity in compression [MPa] (b) Results from the shear modulus test method

number	A [mm]	B [mm]	$E_{C,STN\ EN}$	$E_{C,EXP}$
17	100	100	197.220	210.592
7	100	150	271.634	278.132
16	100	100	83.194	88.745
6	100	150	99.981	100.851
15	100	100	102.264	105.549
5	100	150	131.838	132.615
14	100	100	490.321	520.885
4	100	150	749.511	757.682

number	A [mm]	B [mm]	T_q [mm]	A [mm^2]	$G_{STN\ EN}$ [MPa]	G_{Ansys} [MPa]	G_{exp} [MPa]
17	100	100	30	10000	0.9 ±0.15	0.97	1.16
7	100	150	30	15000	0.9 ±0.15	1.13	1.22
16	100	100	35	10000	0.9 ±0.15	0.94	0.98
6	100	150	35	15000	0.9 ±0.15	0.99	1.02
15	100	100	35	10000	0.9 ±0.15	0.87	0.89
5	100	150	35	15000	0.9 ±0.15	0.94	0.97
14	100	100	10	10000	0.9 ±0.15	1.24	1.32
4	100	150	10	15000	0.9 ±0.15	1.37	1.39

Tab. 4 Results from the restoring moment test method

number	σ_z [MPa]	α [‰]	$M_{STN\ EN}$ [kNm]	M_{ANSYS} [kNm]	M_{exp} [kNm]
17	7	3	0.037	0.101	0.122
7			0.064	0.093	0.139
16			0.008	0.031	0.089
6			0.013	0.055	0.076
15			0.018	0.074	0.119
5			0.032	0.077	0.079
14			0.092	0.144	0.178
4			0.161	0.181	0.195

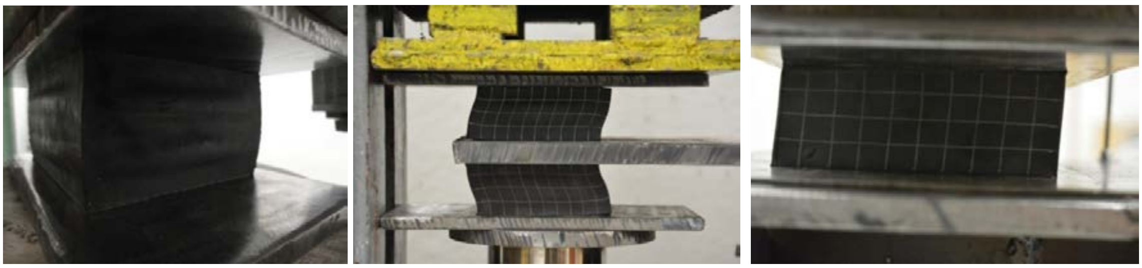

Fig.12 (a) Bearing under a compressive load (b) Bearing under a shear load (c) Bearing under a bending moment load

5. Conclusion

The aim of this paper was demonstrate a behavior of reinforced elastomeric bearings under various loading types. Experimental testing was carried out to verify the interaction of reinforced elastomeric bearings in bridge construction. The resulting values of the parameters obtained were compared with the values from numerical modeling by FEM and the values estimated from standard STN EN 1337-3. The values from the numerical modeling were almost always between the other two methods. In the experimental testing were result values of vertical deflection from compression test method on the safe side (expect number of bearing 5, 14, 15). The values calculated according to standard [1] were higher, so this part of the standard also has a correct assumption. For the calculation of values of modulus of elasticity in compression has standard also correct assumption. The resulting values of the shear modulus from the experimental testing and numerical modeling were always higher than the standard assumed. The most important was the behavior of reinforced bearings under a moment load test. The values of the restoring moment from experimental testing and numerical modeling were much higher than those from calculated by the standard. The main reason for this difference is the independence of the restoring moment from the amount of the compressive stress. The second reason was an assumption of the linear behavior of the bearings under all types of loads according to the standard, which proved to be incorrect. Other reasons could be inaccurate measurements or a simplified load system. On the other hand, these results are in accord with those from the numerical modeling. The formulas in the standard should be modified by the results from experimental studies, but that could be expensive. In a comparison of two types of bearings is higher difference only by the compressive testing method. Vertical deflections of bearing type 1 are two times higher than type 2, due to the outer steel plates with a thickness 15mm, which increases the vertical stiffness of the bearing.

Acknowledgements

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